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The application is published incomplete as filed (Article 93 (2) EPC). The point in the description or the claim(s) at which the omission obviously occurs has been left blank.

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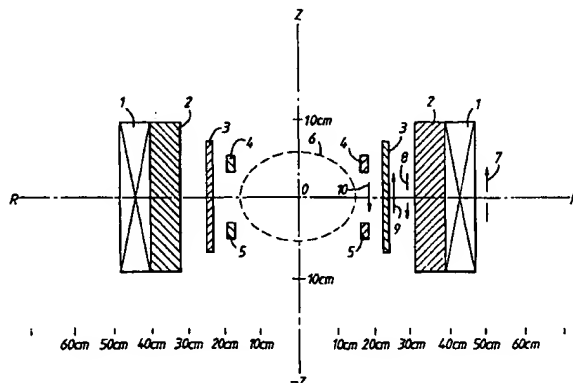
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(54) **Improvements in or relating to MRI magnets.**

(57) An MRI magnet arrangement comprises, an annular electro-magnet defined by a coil (1,7), an annular shim of magnetic material (2,8) coaxially disposed within the coil, first permanent magnet means (3,9) having a field, the direction of which (9) is the same as the field (7) of the coil (1), disposed coaxially within the said shim and second permanent magnet means (4,5) disposed coaxially within the

said first permanent magnet means, the field of which (10) is arranged to be opposite in direction to the field (9) produced by the said first permanent magnet means, the arrangement being such that the magnetic field produced in an imaging volume (6) within the said second permanent magnet means is substantially homogeneous.

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This invention relates to magnets of the kind used for magnetic resonance imaging (MRI) and more especially it relates to magnets having a short axial length.

In order to provide good image resolution, an MRI magnet must have a suitably sized region, known as the imaging volume, wherein the magnetic field is highly homogeneous such that harmonic coefficients appertaining to the field are substantially zero up to at least the eighth order.

High magnetic field homogeneity and a suitable sized imaging volume are comparatively easy to achieve in elongate annular magnets wherein the axial length of the magnet is long compared with the inner diameter of the magnet. Such magnets, having a length of about 2 metres and a clear bore diameter of about 1 metre, which may be cryogenic electro-magnets, are commonly used for whole body scanning apparatus.

Although these relatively long magnets are generally acceptable, short magnets are to be preferred for some diagnostic purposes such as interventional radiology, and mammography for example. Short magnets also increase the chance of scanning claustrophobic patients.

It is therefore an object of the present invention to provide a relatively short magnet which is suitable for use in MRI apparatus.

According to the present invention an MRI magnet arrangement comprises, an annular electro-magnet defined by a coil, an annular shim of magnetic material coaxially disposed within the coil, first permanent magnet means having a field, the direction of which is the same as the field of the coil, disposed coaxially within the said shim and annular magnetic material disposed coaxially within the said first permanent magnet means, the field of which is arranged to be opposite in direction to the field produced by the said first permanent magnet means, the arrangement being such that the magnetic field produced in an imaging volume within the said annular magnetic material is substantially homogeneous.

The annular magnetic material may comprise magnet means or alternatively it may comprise mild steel, which would be magnetised by the main magnetic field generated by the coils. This is probably a more cost-effective method of building the magnet than using a permanent magnet.

The imaging volume may be substantially elliptical.

The shim may be arranged to serve as a former on which the coil is wound and may be made of Silicon Iron (SiFe), laminated and slotted to remove eddy current

It is well known that the magnetic field due to a coil or ring of magnetic material may be written in terms of a series of Legendre polynomials. The

coefficients in the series refer to particular orders of inhomogeneity in the magnetic field, and so one speaks of Z₂, Z₄, Z₆, etc.. The relative size of the harmonics Z₂, Z₄, Z₆, etc due to a magnetic source depends strongly on the distance between the source and the point at which the magnetic field is measured. So for example in the magnet proposed in this size), a magnet comprises an annular coil 1 which serves as an electro-magnet, the coil being wound on an annular soft iron shim 2 which is disposed coaxially within the coil 1. Disposed coaxially within the annular shim 2, there is provided an annular magnet 3, and within the annular magnet 3 there are provided two further annular magnets 4 and 5. The magnets 4 and 5 are symmetrically and coaxially disposed with respect to the annular magnet 3.

The arrangement is such that a resultant magnetic field is produced within the magnets 4 and 5 in an imaging volume as shown within a broken line 6, which is substantially homogeneous. This homogeneity of the field in the imaging volume, is achieved by arranging that the harmonic coefficients appertaining to the field are substantially zero up to at least the eighth order. In order to aid a better understanding of how this advantageous result is achieved, magnetic field contributions made by the individual parts will now be considered in more detail.

Referring again to the drawing, the coil 1 is arranged to produce a field having a direction as indicated by an arrow 7. As will be well understood by those skilled in the art, the dominant harmonic contributions afforded by this field are Z₀ and -Z₂. In order to shim out the unwanted Z₂ harmonics the annular shim 2 is provided, but as well as compensating for -Z₂ it additionally provides a significant contribution of the harmonic -Z₄. The field due to the annular shim 2 is shown by the arrow 8. In order to shim out the -Z₄ harmonic, the permanent magnet 3 is provided having associated with it a field the direction of which is indicated by an arrow 9. The magnet 3 is chosen so as to provide an equal and opposite contribution of the harmonic -Z₄ introduced by the annular shim 2. It will be appreciated that the magnet 3 also makes a Z₀ and -Z₂ contribution which is taken account of in the sizing of the coil 1 and the annular shim 2. Additionally however, the magnet 3 makes a -Z₆ harmonic contribution and a +Z₈ harmonic contribution. In order to shim out these undesirable harmonics, the annular magnets 4 and 5 are provided which have associated with them a field as indicated by the arrow 10, the direction of which is in opposition to the field provided by the magnet 3. The effect of the magnets 4 and 5 is thus to reduce to substantially zero the harmonics Z₈ and Z₆.

In an alternative embodiment of the invention the magnets 4 and 5 may be replaced with soft iron or silicon iron annuli which may be laminated or slotted to reduce eddy currents.

By using the various component parts of the magnet as hereinbefore described progressively to shim out the significant even harmonics which are responsible for non-uniformities of field, a very short annular magnet has been produced having a substantially elliptical imaging volume which is eminently suitable for MRI mammography or orthopaedic applications. The annular magnet shown is capable of producing a substantially homogeneous field in the imaging volume of about .2T using Neodymium Iron Boron magnets and a soft iron annular shim.

With currently available permanent magnet materials, magnets according to the present invention are probably limited to relatively low field designs since in the presence of high fields the permanent magnet material would tend to be de-magnetised.

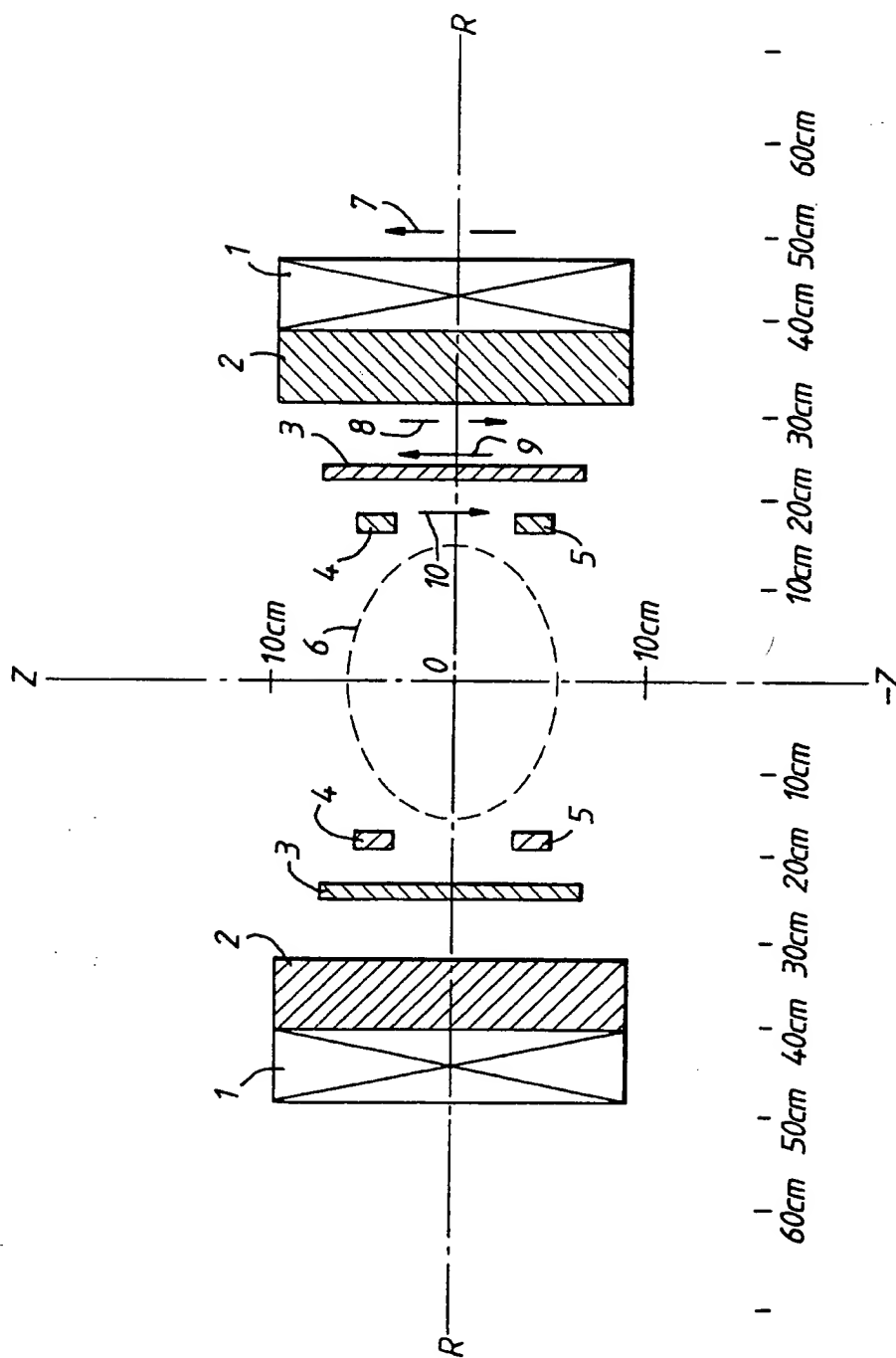
Various modifications may be made to the arrangement just before described without departing from the scope of the invention, and for example, the precise number, size and position of the magnets used may be varied to achieve equivalent results.

Claims

1. An MRI magnet arrangement comprises, an annular electro-magnet defined by a coil, an annular shim of magnetic material coaxially disposed within the coil, first permanent magnet means having a field, the direction of which is the same as the field of the coil, disposed coaxially within the said shim and annular magnetic material disposed coaxially within the said first permanent magnet means, the field of which is arranged to be opposite in direction to the field produced by the said first permanent magnet means, the arrangement being such that the magnetic field produced in an imaging volume within the said annular magnetic material is substantially homogeneous.
2. A magnet arrangement as claimed in claim 1, wherein the said shim is arranged to serve as a former on which the coil is wound.
3. A magnet arrangement as claimed in claim 2, wherein the said first permanent magnet means comprises one annular magnet.
4. A magnet arrangement as claimed in any preceding claim wherein the said annular magnetic material comprises a pair of axially spaced annular magnets, symmetrically dis-

posed with respect to the said first annular magnet means.

5. A magnet arrangement as claimed in any preceding claim wherein the permanent magnets are made of Neodymium Iron Boron (NbFeB).
6. A magnetic arrangement as claimed in any of claims 1 to 3, wherein the said annular magnetic material comprises a pair of axially spaced annuli symmetrically disposed with respect to the said first annular magnet means.
7. A magnet arrangement as claimed in claim 6, wherein the said annuli are made of soft iron, or Silicon iron.
8. A magnet arrangement as claimed in claim 7, wherein the said annuli are slotted or laminated thereby to reduce eddy currents.
9. A magnet arrangement as claimed in any preceding claim wherein the annular shim of magnetic material is made of soft iron.
10. A magnet arrangement as claimed in claim 9, wherein the said shim is slotted or laminated thereby to reduce eddy currents.
11. A magnetic resonance imaging system including a magnet as claim in any preceding claim.





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EUROPEAN SEARCH REPORT

Application Number
EP 93 11 8633

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cls)
A	WO-A-88 08126 (OXFORD MAGNET TECHNOLOGY LIMITED) * page 1, line 30 - page 5, line 2 * * page 11, line 11 - page 13, line 17; figures 2,5 * ---	1,2,9-11	G01R33/38 G01R33/40
A	WO-A-92 07278 (MAGNETECH) * abstract * * page 6, line 3 - page 7, line 27; figures 1,2 * ---	1,2,6,11	
A	GB-A-2 184 243 (PICKER INTERNATIONAL LIMITED) * page 1, line 5 - page 2, line 24; figures 1-4 * ---	1-4,6,7,11	
A	US-A-4 931 760 (J. YAMAGUCHI ET AL.) * column 5, line 17 - column 6, line 30 * ---	1,5,11	
A	EP-A-0 216 404 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN) * page 1, line 16 - page 4, line 7; figures 1,2A * ---	1-4,11	TECHNICAL FIELDS SEARCHED (Int.Cls)
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 327 (P-415) (2050) 21 December 1985 & JP-A-60 151 545 (HITACHI SEISAKUSHO K.K.) 9 August 1985 * abstract * ---	1-4,11	G01R H01F
A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 29 (P-540) (2476) 28 January 1987 & JP-A-61 200 451 (SANYO ELECTRIC CO. LTD.) 5 September 1986 * abstract * ---	1,11	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 24 June 1994	Examiner Horak, G
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document	



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Application Number
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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A,P	GB-A-2 262 611 (GENERAL ELECTRIC COMPANY) * abstract * * page 4, line 23 - page 6, line 20; figures 1-3 * -----	1,11	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 24 June 1994	Examiner Horak, G
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			